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Low-Power Radioisotope Power Systems for Future Smaller Spacecraft and Low-Cost Missions

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INTRODUCTION

Radioisotope Power Systems (RPS) enable many deep space missions, particularly outer planet missions, where increased heliocentric distances reduce the ability of solar power to adequately meet spacecraft requirements. The existing Multi-Mission Radioisotope Thermal Generator (MMRTG) offers >100 We with a mass of > 30 kg. The RPS Program is exploring mission applications for lower power unit sizes which may enable deep space missions with lower power requirements and stricter mass and volume-constraints, such as SmallSats and CubeSats. Low-cost, low-mass, low-power and long-lived applications are being examined as a part of a wider study of potential applications which may not be feasible with the available ~100 We RPS option.

Recently, the RPS Program studied a network of Mars polar region landers using thermoelectric devices to produce 40 mWe from the 1.0 Wth radioisotope heater unit (RHU) that has flown on numerous missions to provide localized heat to thrusters and mechanisms. The low mass and small size of the RHU-RPS has potential application to smaller deep-space spacecraft with limited power demands. The use of these RHU-based power systems allows consideration for more challenging destinations where solar power might become prohibitive on smaller spacecraft.

A study was performed to assess representative missions that would be enabled by such lower power RPS systems. The study selected was: MASER: A Mars Meteorology and Seismology Mini-Network Mission Concept Enabled by Milliwatt-RPS [1], lead by Dr. Ralph Lorenz, study team Science P. I. and performed by the Glenn Research Center's COncurrent Multidisciplinary Preliminary Assessment of Space Systems (COMPASS) Team.

REPRESENTATIVE RHU-RPS

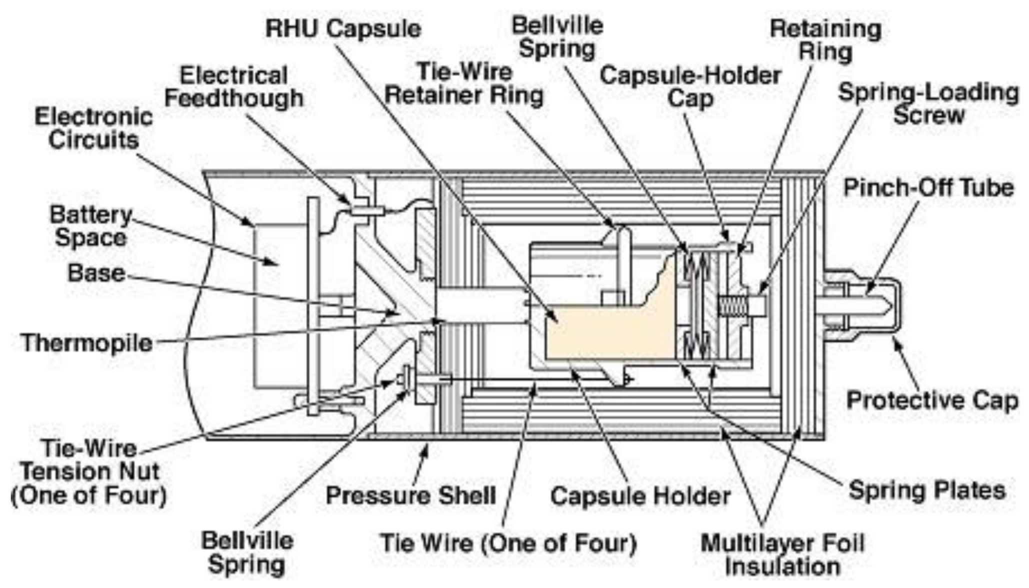

Fig. 2: Hi-Z RHU Based RPS

The MASER Study utilized the HI-Z, high-g load design shown above. The RHU is supported by titanium wires to provide the high-g capability required by the MASER lander design (600g). The RHU is also insulated with multilayer foil insulation directing the heat through the thermoelectric elements (thermopile). Spring loading maintains mechanical and thermal contact to the hot side of the thermopile. The enclosure acts as the thermopile cold-side heat rejection and mounting fixture. The unit produces ~ 5.0 VDC. The outer case is sealed which allows operation in planetary environments, such as Mars. The RHU-RPS unit weighs 0.33kg and is 64mm in diameter and 123mm long.

POWER SYSTEM DESIGN

Load	Power (mWe)	Duty Cycle	Total Energy (mW-hrs)
Housekeeping	50	100	1560
Pressure/Temp	2	100	62
Seismometer	50	100	1560
Wind Sensor	250	8	650
Optical Monitor	20	8	52
Transmitter	2500	1	1100
Capacitor Self-Discharge	15	100	360

Fig. 5: Power and Energy Demand

MASER's power demand and subsequent instrument duty cycles shown in Fig. 5 required a total of 6- RHU-RPS units (240 mWe) and ultracapacitors for the high power demand transmit mode.

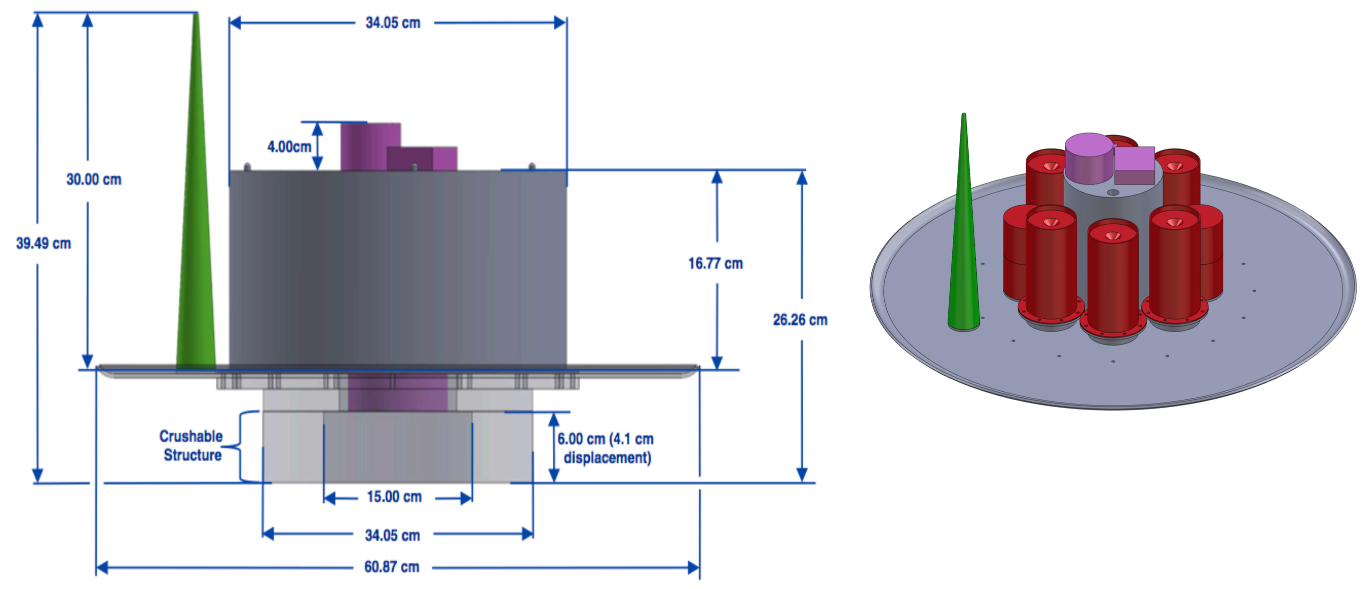

Fig. 6: View of Lander showing 6 RHU-RPS Units w/Ultracapacitors

RHU DESCRIPTION

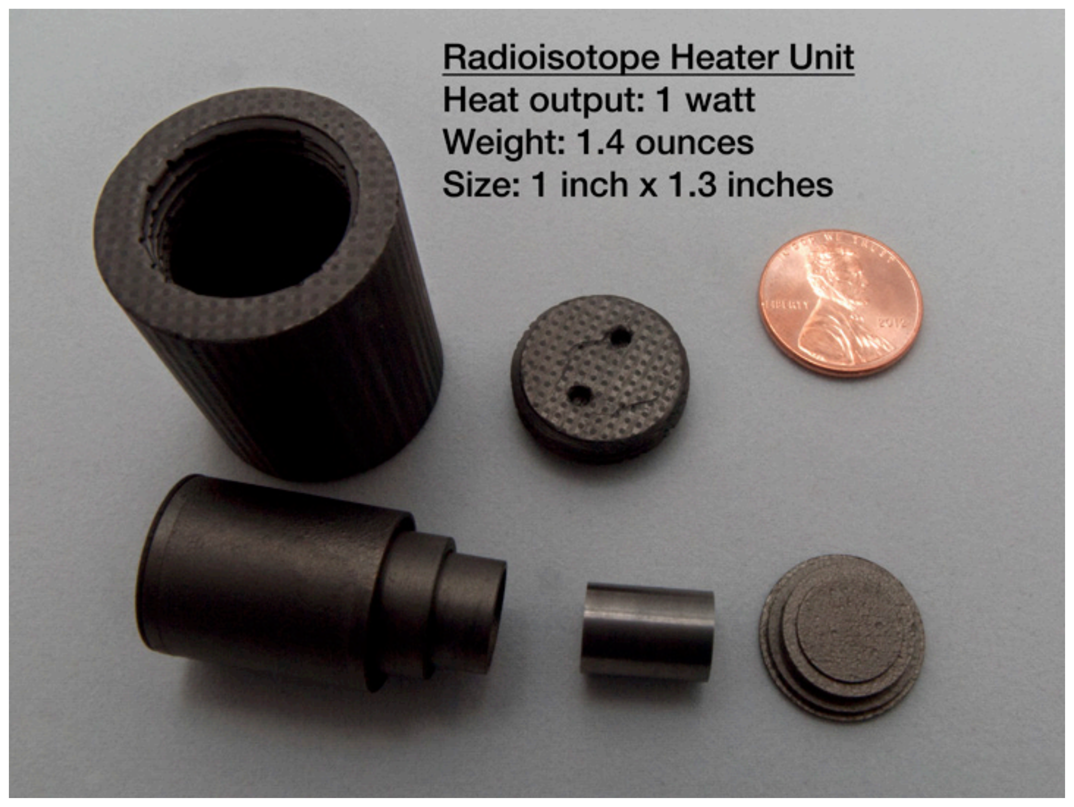

Fig. 1: Expanded view of a radioisotope heater unit (RHU)

The characteristics of the RHU are shown in Fig. 1. The fuel pellet (lower middle) contains 2.7 gm of $^{238}PuO_2$ providing approximately 1.0 watt of thermal power due to the ~88 year half-life natural decay of the plutonium-238. The pellet in encased in insulation and placed in an outer graphite aeroshell. This particular design was used on the Cassini Mission and Huygens Probe, Mars Pathfinder and MER Rovers, *Spirit* and *Opportunity*.

The RHU could provide heat similar to the heat sources used to power the MMRTG now powering *Curiosity* rover and also planned for Mars 2020. The same concept employed on the MMRTG and past RPS missions, can be utilized with the RHU to produce low-level power utilizing thermoelectric heat-to-electric conversion devices. The 1.0 watt thermal output could produce power in the 10's of mWe with current thermoelectric technology.

The RHU-RPS is assumed to have the same mass, volume and performance as a system prototyped in the last decade by Hi-Z [2, 3]. Importantly for the MASER estimated 600 g landing load, this RHU-RPS system was impact-tested (in connection with the proposed Pascal mission development) and tolerated >2,000g along the generator axis, and > 700g at 45° impact angle [2, 3].

1. Lorenz, R., MASER: A Mars Meteorology and Seismology Mini-Network Mission Concept Enabled by Milliwatt-RPS, 2014 IEEE Aerospace Conference, Big Sky MT, March 2014
2. Bass, J; Hiller, N; Jovanovic, V; Elsner, N: "Multi-Mission Capable, High g Load mW RPS: Final Report", Office of Space and Defense Power Systems, DOE, May 2007
3. 2. Allen, D. T., N. D. Hiller, J. C. Bass and N. B. Elsner. Fabrication and Testing of Thermoelectric Modules and Milliwatt Power Supplies, Proceedings of the Space Technology and International Forum (STAIF), Albuquerque, February 2004.

MASER MISSION DESIGN

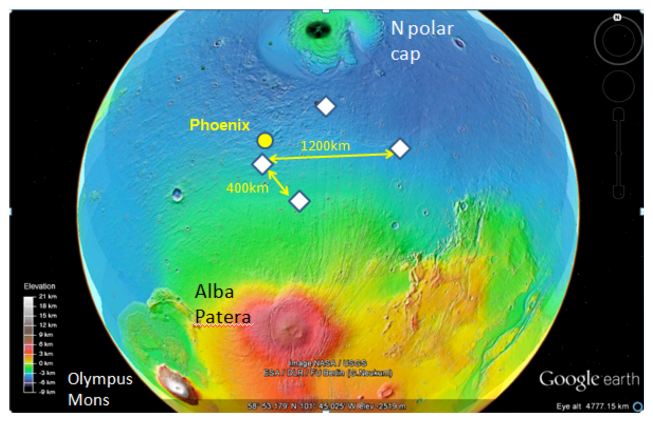

Fig. 3: Four stations (white diamonds) would be delivered to the northern plains between the heavily-tectonized flanks of the Alba Patera volcano and the north polar cap. Inter-station distances range from 400-1,200km.

Instrument	Measurement/Rationale	Basis	Mass (kg)	Dimensions/Configuration/ Mounting
Pressure / Temperature	Seasonal pressure cycle, atmospheric tides, cyclonic systems, dust devils. MEMS diaphragm pressure sensor or ion current gauge	Phoenix, Mars-96	0.07	Internal sensor, enclosure must be vented. Stable temperature essential. 1.5x2x2cm / 1x1x1cm
Seismometer	Seismic monitoring (short period seismic signals only). MEMS micro-seismometer or Ranger/Lunar-A geophone type.	Lunar-A, Ranger, Insight	0.5	Forebody (for minimal wind effects and maximum seismic coupling). 10cm x 10cm diameter
Optical Monitor	Set of windowed up-looking photodiodes/filters to measure UV/near-IR light levels for water vapor, cloud, dust loading	Beagle / Mars-96/ MSL	0.1	Top side, sky view 2x6x5cm
Accelerometer Package	MEMS. Atmosphere profile during entry/ descent. Surface mechanical properties; post-impact tilt.	DS-2	0.05	Entry/Tilt accel near c.g. Impact accel in forebody 1cm^3 each.
Wind	Hot film anemometer. Seasonal, synoptic and diurnal weather systems, dust devils and gusts.	Beagle/ MSL	0.15	Top side, minimal azimuthal obstruction 4cm x 6cm diameter

Fig. 4: Science Payloads

The operation of the four identical landers occur essentially autonomously for MASER's baseline 2 year mission. After EDL and seismometer deployment, the vehicles simply acquire data while trickle-charging their capacitors. When an over-flight occurs with an Mars orbiter the lander transmits the data to the orbiting relay in view via a UHF link.

Knowing the extremely low power output of the RHU-RPS the strategy for the lander was to allow continuous low power measurements and housekeeping functions while storing energy for the high power loads which would be operated periodically. Specifically the pressure, temperature sensors and seismometer would operate continuously while the wind sensor, optical monitor and communication system would operate periodically. This is necessary to provide context to the seismometer data with and without wind disturbance.

The RHU-RPS's continuous power output allows day/night operation during all four Martian seasons. The insulated lander and ~ 6.0 Watt thermal output of the 6 RHU-RPS units, provides sufficient keep alive environment for lander electronics.

SUMMARY

The study identified a design reference mission (MASER–Meteorology and Seismology Enabled by Radioisotopes) for a Mars mini-network enabled by radioisotope power system technology. Four hard landers, delivered to Mars on a carrier cruise stage, using parachutes and crushable impact attenuators would be deployed in the polar plains north of the Tharsis bulge to perform seismic and meteorological measurements throughout a Martian year (including the dark winter). Operation throughout the polar winter is only possible through the use of a power source using six RHU-RPS, providing ~240 mWe**.**

The success of such a mission is only possible utilizing both the electric power and the heat provided by RPS technology. The MASER lander would certainly not survive over the Mars winter without the thermal power within a highly insulated spacecraft. In this particular case, every watt of thermal power eliminated the need for equivalent electrical heater power reducing mass, complexity and overall electrical load on the power system, similar to the *Curiosity* rover's recovery of heat from the MMRTG.

The advent of smaller spacecraft and lower cost missions drives to lower powers and reduced masses. As small satellite or cubesat technology systems advance, missions to more challenging destinations beyond earth orbit are likely to come about. RPS offers the advantage of power independent of distance from the Sun or long dark periods experience on planetary bodies.

The MASER study used the Hi-Z system previously developed due to its demonstrated high g characteristics and more mature development. However, higher power units using multiple RHUs have been assessed in the past. While the MASER lander required 240 mWe, the design of the lander was better suited to having 6 smaller units than one larger unit. In addition, high g capability may not be necessary for many missions.

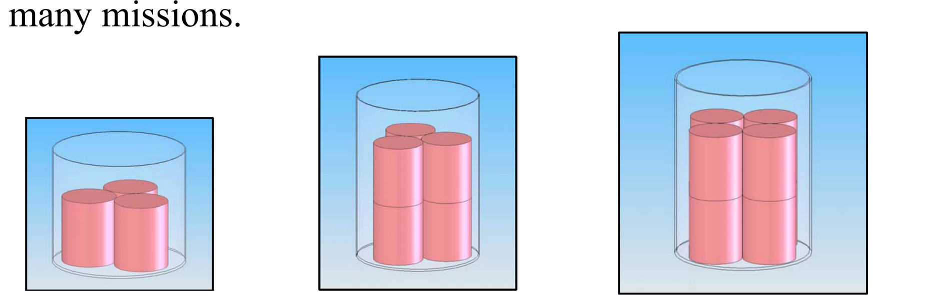

Fig. 7: Conceptual Layout of Multi-RHU-RPS [2]

Figure 7 illustrates some potential configurations of higher power RHU-RPSs. The electric power outputs of these concepts would be 120 mWe, 240 mWe and 320 mWe, respectively and illustrates a path toward future developments. These concepts also preserves the RHU unit of Figure 1 and could maintain the all the safety analysis and testing previously established.

More detailed study would be required to determine the optimum configuration and thermoelectric module design.